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Alkaline Battery Division

GULTON INDUSTRIES, INC.

Metuchen, N. J.

t: DESIGN, DEVELOPMENT AND MANUFACTURE

OF STORAGE BATTERIES FOR FUTURE

SATELLITES VI, Quarterly... Report No. 6, 4 Feb. - 4 May 1962

Report No. 6

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION NASA ~~- CONTRACT NO.~~ NAS - 5-809 (NASA CR-55646) OTS:

SIXTH QUARTERLY PROGRESS REPORT

4 February 1962 to 4 May 1962

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Metuchen, New Jersey N.J.

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I. ABSTRACT

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The pilot plant process line has been refined and streamlined to produce reliable hermetically sealed cells with ceramic-to-metal seals. These cells are finding increased use in satellite applications.

Continued work on the thermal aspects of sealed cells has resulted in a laboratory study of thermal resistances inside a cell. A mathematical analysis of heat flow in a cell shows that there is a particular set of cell dimensions which is most unfavorable from a thermal viewpoint and should be avoided in cell design.

Based on thermal and mechanical considerations the 50 AH cell has been redesigned and prototype cells are being built.

Thin plate 5AH cells have been fabricated and are being tested. These cells are in the VO-6 HS cell container which has been reduced in height. Electrical testing will reveal if thin plate cells show a significant advantage over the 35 mil plates now being used.

Author

II. CORRECTION

In the Fifth Quarterly Report on this contract, in Section II, we reported on cells of the VO-6 HS type delivered to NASA Goddard. It would appear that these cells were delivered under Contract NAS 5-809, but actually 110 cells were procured under a separate order NAS 5-1583.

III. PILOT FACILITY

In the Fourth Quarterly Report under this contract, a flow sheet was depicted showing the process flow stream in the pilot plant where the hermetically sealed cells are produced.

As a result of operating the pilot line for several months, several modifications in the process have been found feasible, and have been instituted. A revised flow sheet is shown in Figure 1.

As before, complete inspection at all stages of manufacture continues to be stressed.

During the past quarter, progress has been made in converting the VO-6 HS design to a drawn can. The drawing dies have been fabricated, and initial samples have been delivered. Some modifications to the tool are still required to produce a perfectly smooth can within the required tolerances. It is expected that the drawn can will soon be available for VO-6 HS cell production.

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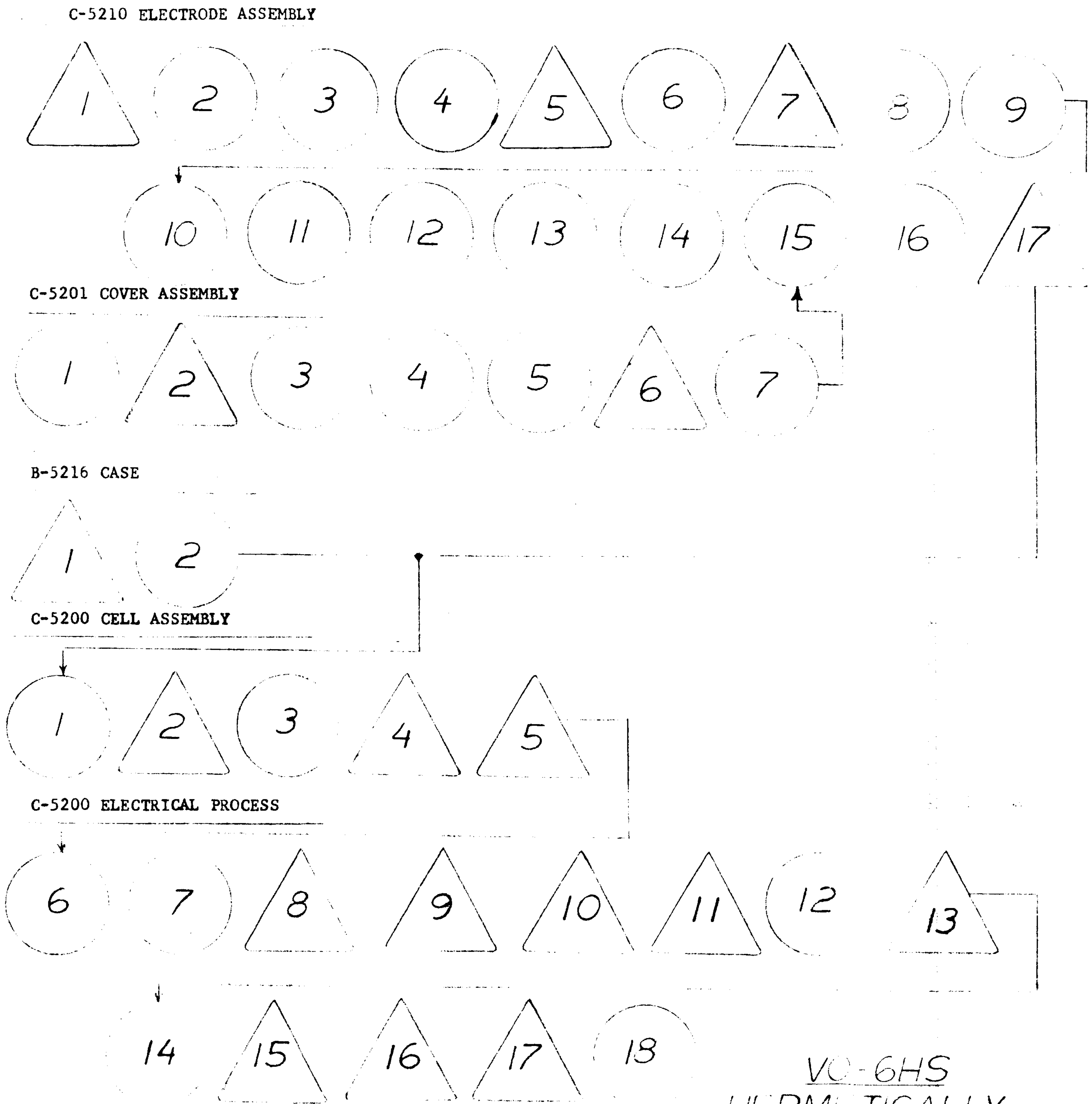
FIGURE 1



VO-6HS
HERMETICALLY
SEALED CELLS
FLOW CHART

LEGEND

C-5210 ELECTRODE ASSEMBLY

1. M&V Insp.
2. Coat Edges
3. Temp. Wrap
4. Formation
5. Test Capacity
6. Wash Plates
7. Test Neutrality
8. Dry Plates
9. Coat Edges
10. Trim Tabs
11. Assemble Plates to Combs
12. Spot Weld Plates to Combs
13. Spot Weld Support to Neg. Comb
14. Heliarc Weld Support to Comb
15. Spot Weld Cover to Pack
16. Final Wrap
17. Test Compression

C-5201 COVER ASSEMBLY

1. Weld Pinch Tube to Cover
2. Test Pinch Tube Seal
3. Paint Parts with Activating Material
4. Assemble Positive Terminal to Cover
5. Seal Terminal to Cover
6. Test Cover Seal
7. Weld Negative Terminal to Cover

B-5216 CASE

1. Test Case
2. Wash Case

C-5200 CELL ASSEMBLY

1. Insert PVC and Assembly into Case
2. Short Test Cell Assembly
3. Weld Cover Assembly to Case
4. Short Test Welded Assembly
5. Leak Test Complete Cell Assembly

C-5200 ELECTRICAL PROCESS (CONT'D)

6. Number Cells, Fill with KOH, Assemble Gauge, Wash and Dry, Assemble Pressure Jacket
7. Discharge and Evacuate Air
8. Place on 24 Hr. Charge, Test with Pheno, Pressure & Voltage
9. Test Cycle for Pressure
10. Test Pheno., Pressure & Voltage
11. Test Capacity
12. Fill with 5% Helium and 95% Oxygen, Cut Pinch Tube, Crimp and Weld
13. Test Shorted OCV is Recorded
14. Remove Pressure Jacket, Clean & Stamp, Assemble Pressure Jacket
15. Charge, Test for Helium, Test with Pheno.
16. Test Voltage & Capacity
17. Final Mechanical Visual
18. Package and Ship.

M0951

IV. THERMAL ANALYSIS

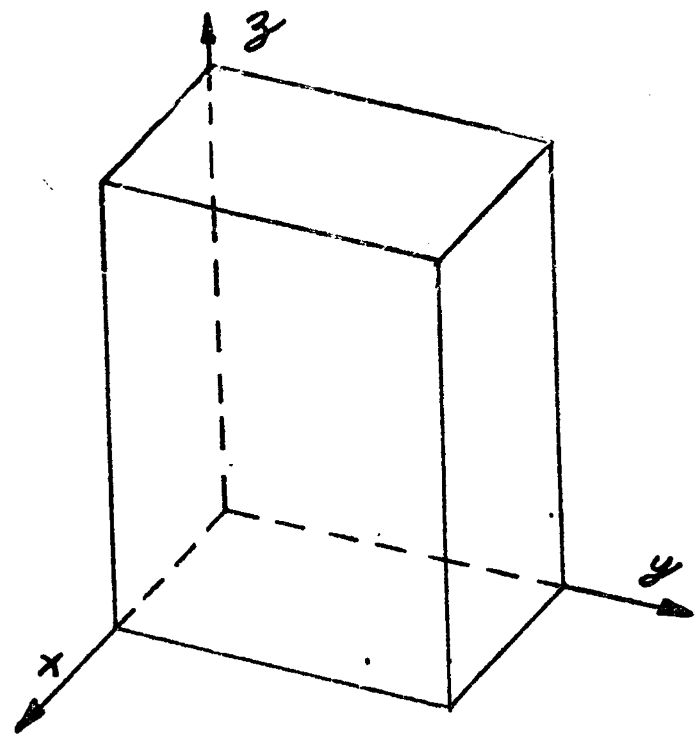
A. THERMAL RESISTANCE

It was noted from previous data that the mean skin temperature on all six sides of a cell were identical at a specific environmental condition and overcharge rate. This caused the temperature difference from the center of the cell to the skin to be the same in all three directions. An experimental investigation was undertaken to determine the magnitude of the thermal resistance in the three directions. This was accomplished by placing a known heat source on one face of the cell and insulating it and four other faces so that the flow of heat would be unidimensional. The thermal gradient in the direction of heat flow was measured which enabled one to determine the thermal resistance in one direction. The same procedure was followed to determine the thermal resistance in the other two directions. It was found that the thermal resistances in the x, y, and z directions are 0.377 $\frac{HR\ ^{\circ}F}{BTU}$, 1.175 $\frac{HR\ ^{\circ}F}{BTU}$, and 2.22 $\frac{HR\ ^{\circ}F}{BTU}$, respectively. It was also found that the resistance was such as to produce an identical temperature differential along each of the three axes of the cells.

In a further investigation it was found that a minimum of $\left(\frac{1}{Rcq}\right)$ existed in which the worst possible dimensions are obtained. Within practical means, consistent with current manufacture practice, this configuration is to be avoided. It can be seen from this that the flat cells offer much less thermal resistance than do the squat cells. This information will aid the battery manufacturer in not only designing a cell for electrical characteristics, but also for thermal considerations.

B. Effect of Cell Dimensions on Heat Transfer Rates — A Mathematical Analysis

An attempt was made to ascertain whether there exists one set of cell dimensions which would minionize the heat resistance out of the cell in the three dimensions as shown in the figure. The effect of cell dimensions on heat transfer was analyzed mathematically.



$$q_x = \frac{K_x A \, \Delta T_x}{\Delta x} = \frac{\Delta T}{\left(\frac{\Delta x}{K_x A}\right)}$$

THIS IS ANALOGOUS TO

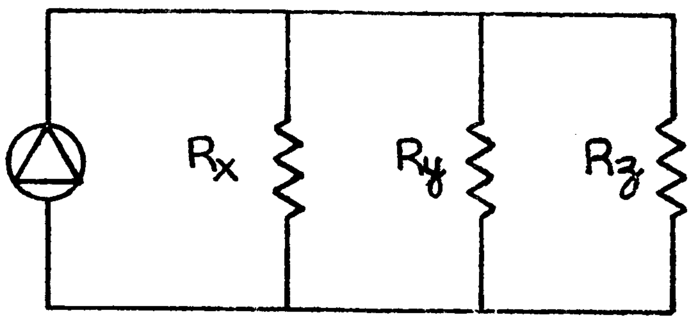
$$I_x = \frac{E}{R}$$

$$\therefore \quad R_x = \frac{\Delta x}{K_x A} = \frac{x}{K_x y z}$$

$$R_y = \frac{y}{K_y x z}$$

$$R_z = \frac{z}{K_z x y}$$

SINCE THE TEMPERATURE POTENTIAL IN ALL THREE MUTUALLY PERPENDICULAR DIRECTIONS IS THE SAME. ($\Delta T_x = \Delta T_y = \Delta T_z$; OR $E_x = E_y = E_z$) WE CAN SIMULATE THE HEAT FLOW PHENOMENON BY AN EQUIVALENT ELECTRICAL CIRCUIT.



TO GET AN EQUIVALENT RESISTANCE

$$\frac{1}{R_{eq}} = \frac{1}{R_x} + \frac{1}{R_y} + \frac{1}{R_z} = \frac{R_y R_z + R_x R_z + R_x R_y}{R_x R_y R_z}$$

$$\frac{1}{R_{eq}} = \frac{\dfrac{\cancel{yz}}{K_y K_z x^2 \cancel{yz}} + \dfrac{\cancel{xz}}{K_x K_z \cancel{x} y^2 \cancel{z}} + \dfrac{\cancel{xy}}{K_x K_y \cancel{xy} z^2}}{\dfrac{\cancel{xyz}}{K_x K_y K_z x^2 y^2 z^2}}$$

$$\frac{1}{R_{eq}} = K_x K_y K_z \, xyz \left[\frac{1}{K_y K_z x^2} + \frac{1}{K_x K_z y^2} + \frac{1}{K_x K_y z^2} \right]$$

$$\frac{1}{R_{eq}} = \left[\frac{K_x y z}{x} + \frac{K_y x z}{y} + \frac{K_z x y}{z} \right]$$

THE SYSTEM OBEYS THE EQUATION AND HAS THE FOLLOWING EQUATION of RESTRAINT.

$$\therefore \qquad V = \text{CONST} = xyz$$

WE CAN USE THE METHOD of LAGRANGE TO OBTAIN THE MAXIMUM OR MINIMUM AND LATER TEST TO SEE WHICH WE HAVE.

WE MUST DIFFERENTIATE THE MAIN FUNCTION AND THE RESTRAINING EQUATION, SET THEM BOTH EQUAL TO ZERO, MULTIPLY THE DIFFERENTIATED RESTRAINING EQUATION BY A LAGRANGE MULTIPLIER (λ), COLLECT ALL TERMS WITH THE SAME DIFFERENTIAL.

DIFFERENTIATING MAIN FUNCTION

$$d\left(\frac{1}{R_{eq}}\right) = K_x yz\left(\frac{\partial \frac{1}{x}}{\partial x}\right)_{yz} dx + K_x \frac{z}{x}\left(\frac{\partial y}{\partial y}\right)_{xz} dy + K_x \frac{y}{x}\left(\frac{\partial z}{\partial z}\right)_{xy} dz +$$

$$K_y \frac{z}{y}\left(\frac{\partial x}{\partial x}\right)_{yz} dx + K_y xz\left(\frac{\partial \frac{1}{y}}{\partial y}\right)_{xz} dy + K_y \frac{x}{y}\left(\frac{\partial z}{\partial z}\right)_{xy} dz +$$

$$K_z \frac{y}{z}\left(\frac{\partial x}{\partial x}\right)_{yz} dx + K_z \frac{x}{z}\left(\frac{\partial y}{\partial y}\right)_{xz} dy + K_z xy\left(\frac{\partial \frac{1}{z}}{\partial z}\right)_{xy} dz$$

$$0 = \left(-\frac{K_x yz}{x^2} + K_y \frac{z}{y} + K_z \frac{y}{z}\right) dx +$$

$$\left(K_x \frac{z}{x} - K_y \frac{xz}{y^2} + K_z \frac{x}{z}\right) dy +$$

$$\left(K_x \frac{y}{x} + K_y \frac{x}{y} - K_z \frac{xy}{z^2}\right) dz$$

DIFFERENTIATING RESTRAINING EQUATION AND MULTIPLYING BY (λ)

$$0 = \lambda xy\,dz + \lambda xz\,dy + \lambda yz\,dx$$

COLLECTING ALL TERMS WITH THE SAME DIFFERENTIAL AND SETTING THEM EQUAL TO ZERO

$$① \quad \lambda yz - K_x \frac{yz}{x^2} + K_y \frac{z}{y} + K_z \frac{y}{z} = 0$$

$$② \quad \lambda xz - K_y \frac{xz}{y^2} + K_x \frac{z}{x} + K_z \frac{x}{z} = 0$$

$$③ \quad \lambda xy - K_z \frac{xy}{z^2} + K_x \frac{y}{x} + K_y \frac{x}{y} = 0$$

$$④ \quad xyz - V = 0$$

WE HAVE FOUR EQUATIONS AND FOUR UNKNOWNS

SOLVING EQUATION (1) FOR λ WE HAVE

$$\lambda = \frac{K_x}{x^2} - \frac{K_y}{y^2} - \frac{K_z}{z^2}$$

SUBSTITUTING λ IN EQUATION (2)

$$\frac{K_x xz}{x^2} - \frac{K_y xz}{y^2} - \cancel{\frac{K_z xz}{z^2}} - \frac{K_y xz}{y^2} + K_x \frac{z}{x} + \cancel{K_z \frac{x}{z}} = 0$$

$$\therefore \cancel{2} K_x \frac{\cancel{z}}{x} = \cancel{2} K_y \frac{x\cancel{z}}{y^2}$$

$$\frac{K_x}{K_y} = \frac{x^2}{y^2}$$

(2a) OR $\dfrac{x}{y} = \sqrt{\dfrac{K_x}{K_y}} = \beta$

SUBSTITUTING λ INTO EQUATION (3) WE HAVE

$$K_x \frac{xy}{x^2} - \cancel{K_y \frac{xy}{y^2}} - \cancel{K_z \frac{xy}{z^2}} - K_z \frac{xy}{z^2} + K_x \frac{y}{x} + \cancel{K_y \frac{x}{y}} = 0$$

$$\therefore \quad \cancel{2} K_x \frac{\cancel{y}}{x} = \cancel{2} K_z \frac{x\cancel{y}}{z^2}$$

$$\frac{K_z}{K_x} = \frac{z^2}{x^2}$$

(3a) OR $\dfrac{z}{x} = \sqrt{\dfrac{K_z}{K_x}} = \alpha$

WE NOW HAVE THREE EQUATIONS THREE UNKNOWNS

(2a) $y = \dfrac{x}{\beta}$

(3a) $z = \alpha x$

(4) $xyz = V$

- SUBSTITUTING EQUATIONS (2a) AND (3a) INTO EQUATION (4)

$$x\left(\frac{x}{\beta}\right)(2x) = V$$

$$x^3 = V\frac{\beta}{2}$$

$$\boxed{x = \sqrt[3]{\frac{\beta}{2}}\quad V^{1/3}}$$

- SUBSTITUTING FOR X IN EQUATION (2a)

$$\boxed{y = \sqrt[3]{\frac{1}{2\beta^2}}\quad V^{1/3}}$$

SUBSTITUTING FOR X IN EQUATION (3a)

$$\boxed{z = \sqrt[3]{\beta 2^2}\quad V^{1/3}}$$

-

FROM PREVIOUS EXPERIMENTAL DATA FOR A NICKEL, CADMIUM, BATTERY.

$$K_x = .136 \ \text{BTU/HR IN } ^\circ F$$

$$K_y = .394 \ \text{BTU/HR IN } ^\circ F$$

$$K_z = .986 \ \text{BTU/HR IN } ^\circ F$$

$$\beta = \sqrt{\frac{K_x}{K_y}} = \sqrt{\frac{.136}{.394}} = .587$$

$$\alpha = \sqrt{\frac{K_z}{K_x}} = \sqrt{\frac{.986}{.136}} = 2.69$$

$$\sqrt[3]{\frac{\beta}{\alpha}} = \sqrt[3]{\frac{.587}{2.69}} = .602$$

$$\sqrt[3]{\frac{1}{2\beta^2}} = \sqrt[3]{\frac{1}{(2.69)(.597)^2}} = 1.028$$

$$\sqrt[3]{\beta 2^2} = \sqrt[3]{(.587)(2.69)^2} = 1.62$$

$$\therefore \quad \boxed{\begin{aligned} x &= .602\,V^{1/3} \\ y &= 1.028\,V^{1/3} \\ z &= 1.62\,V^{1/3} \end{aligned}}$$

V. 50 AH HERMETICALLY SEALED CELL DESIGN

The 50 AH cell design, as outlined in the last report was considered too thick to be practical. There are two considerations which prompted this decision; the first being the size of the case side, which would be difficult to support in a battery configuration; the second being the consideration of heat transfer from within the cell.

A plate having dimensions of 4.6 inches wide x 4.5 inches high in the active area has a theoretical positive capacity of 3.76 AH per plate. With 15 positive electrodes, the theoretical capacity will be 56.4 AH, which allowing for all variation, should give a conservative 50 AH capacity cell.

The dimensions of a cell using this configuration with a compact composit terminal would have the following outside dimensions as shown in Figure 2.

Thickness	1.29 inches
Width	4.81 inches
Height (over case)	5.64 inches

Cell $V = 34.8 \text{ in.}^3$

Cube root of Cell $V = 3.26$ in.

From the heat transfer analysis of the preceeding section, the critical dimensions to be avoided are as follows:

Thickness of Cell	$X = .602 \times V^{1/3}$	$= .602 \times 3.26 = 1.96$ inches
Width of Cell	$Y = 1.028 \times V^{1/3}$	$= 1.028 \times 3.26 = 3.35$ inches
Height of Cell	$Z = 1.62 \times V^{1/3}$	$= 1.62 \times 3.26 = 5.28$ inches

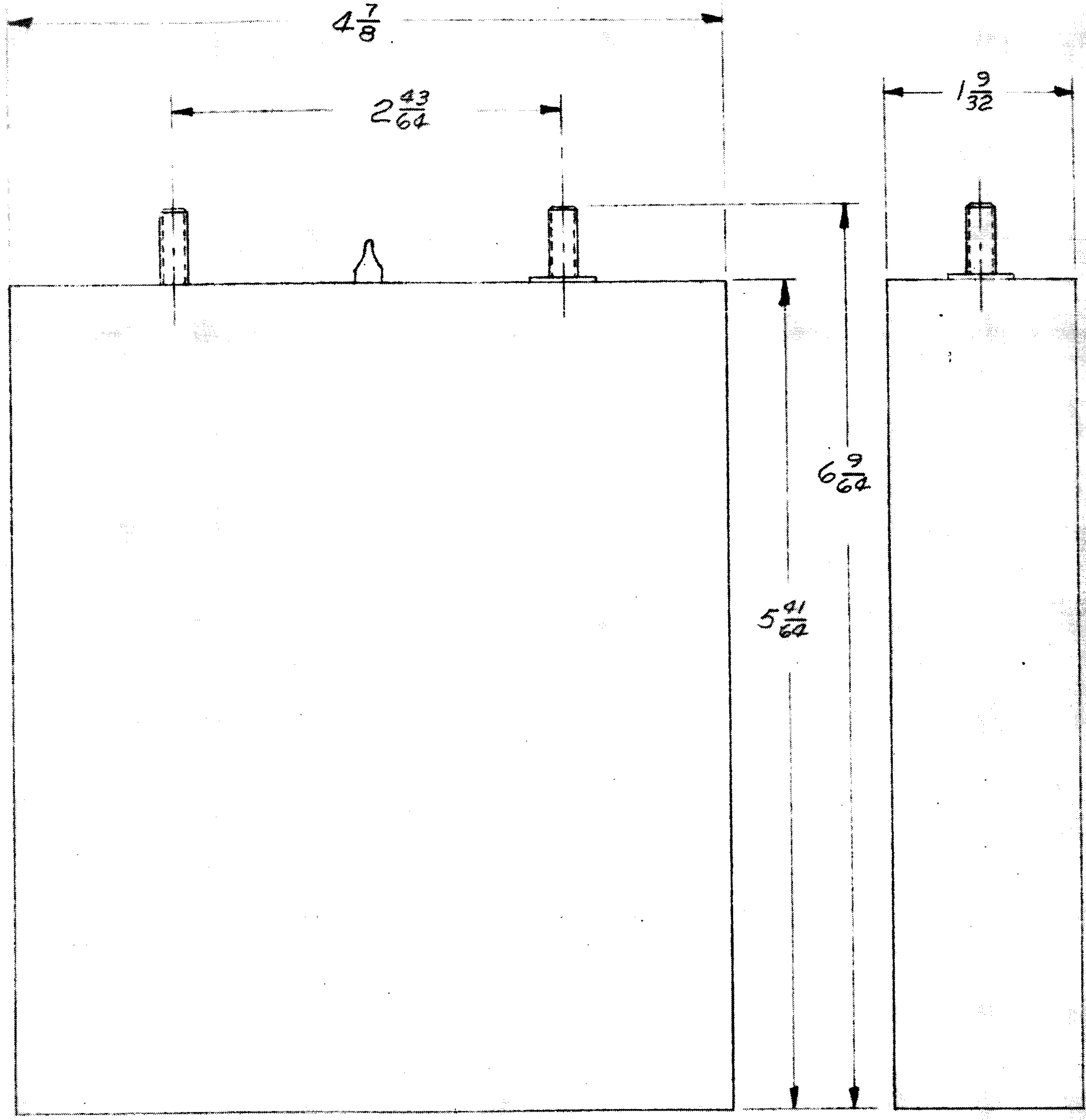
As seen from the above figures, the only dimension approaching the critical dimension is the height, the others are decidedly on the favorable side.

The thickness of the cell is close to the maximum considered practical for unsupported cell sides in a cell of this size. With cell walls of .0319 stock, a maximum cell thickness should be in the order of 1-1/4 inches. This cell is within 0.036 inch of this figure and is considered practical.

A design for a terminal which will be suitable for both solder type and threaded type connection is being considered. Electrically, the soldered type connector is still considered best, but the demand for threaded connections for testing purposes is becoming stronger so that a combination terminal is a possibility.

Prototype construction of this cell will be started during the next reporting period.

FIGURE 2



VO-50HS
HERMETICALLY SEALED
NICKEL CADMIUM CELL

M0950

VI. THIN PLATE CELLS

The presently manufactured hermetically sealed nickel-cadmium cells utilize electrodes having a thickness of 0.035 inch. Thin negative and positive electrodes have been prepared which are 0.025 inch and 0.027 inch respectively. The porosity of these electrodes in the dry discharged state is 21% as compared to 17% for the standard thickness. The increased porosity is expected to result in an increased coefficient of utilization for the active material.

Six cells have been assembled using the thin plates in a construction similar to that of the VO-6 HS cell. The VO-6 HS can has been used, but the overall height is 0.25 inch less. The cells contain 11 positive and 12 negative plates, and the separator is non woven nylon. The capacity of these cells has been calculated to be, conservatively 4.7 ampere hours, based on considerations which originally called for a 5 ampere hour rating for the VO-6 HS cells.

The amount of electrolyte for the cell to function as a hermetically sealed cell has been calculated to be 13.5 ml based on porosity measurements for the plates and separator. Sufficient electrolyte is added to completely flood both the plates and the separator between them.

In standard practice, sealed cells are tank formed flooded before assembly to build up their working capacity. Because of the increased porosity of the thin plates, they are being formed as limited electrolyte cells in the final can. This simplifies the fabrication process.

The six cells have been assembled and are going on to test. Results will be reported at the end of the next quarter.

VII. CONCLUSIONS

1. PILOT FACILITY

The processing stream for cells in the pilot plant has been improved and a new process flow sheet is included in this report. Drawn cans for the VO-6 HS cells have been made and with some minor refinements in the tools this size cell will be available in a seamless container.

2. THERMAL ANALYSIS

Experimental measurements have substantiated that thermal resistances along each cell axis, although different, are of such value as to produce an identical temperature differential along each axis. It has been established that thermal considerations should be carefully evaluated in cell design. A satisfactory thermal design can be checked mathematically by using the design criteria which have been derived.

3. 50 AH CELLS AND THIN PLATE CELLS

Both the large size cells and thin plate cells have been designed and are being built. The thin plate cells are completed. Electrical and mechanical evaluation of these cell designs have been initiated.

VIII. PROGRAM FOR NEXT PERIOD

The main items of effort for the next period will include:

1. Fabricate and test the 50 AH cells.
2. Test and evaluate the thin plate cells.
3. Complete the pilot line to produce hermetically sealed cells.
4. Perfect the drawn can for the VO-6 HS container.

In addition to the above main items, consideration will be given to the following:

1. Means to monitor cell pressure in multicell battery packages.
2. High temperature charge efficiency.
3. Low temperature charge methods.

IX. PERSONNEL

The following personnel have contributed to this effort:

R. C. Shair, Director of Research

J. Carter, Section Head, Development

G. Rampel, Senior Chemist

K. Preusse, Mechanical Engineer

R. Dagnall, Mechanical Engineer

T. Staub, Mechanical Engineer